SOME EXPERIENCES WITH BRASS IN CIVIL ENGINEERING WORKS.

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"Brass" is herein used to mean various copper alloys containing not over 70 per cent. of copper, including many metals commercially denominated bronze of one kind or another. Experiences to be described were had in connection with the unprecedented new water works for New York City, commonly referred to as the Catskill aqueduct. These experiences extend over the period from 1908 to this date.

Because of the importance of the Catskill aqueduct structures and their equipment, and because as time advances interruptions in their use would become increasingly objectionable, earnest efforts were made to secure dependability and permanence, particularly in parts which could not readily be renewed. To this end, the most enduring materials were sought and careful investigations made to determine what was best for each purpose. Having clearly in mind the disadvantages arising from the corrodibility of iron and steel in hydraulic structures and the impractability of preventing their corrosion, a strong, incorrodible metal was sought. No such metal is known of sufficiently low cost to be afforded even by New York City for general water-works uses; consequently, for pipe lines, for most of the large valves and all large sluice gates, and for most structural metal parts the Catskill aqueduct engineers were forced to be contented with iron and steel, protected by the best means and methods discoverable.

Some few kinds of metal parts there were, however, in which the disadvantages of corrosion of iron or steel were so great that

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a relatively large expenditure for a strong incorrodible metal was justified. In most, if not all, these parts it was impracticable, by any known method, to protect iron or steel permanently. Included in this category are: Sluice gate anchors and other bolts, the failure of which would be extremely troublesome; large and small valves of ordinary and special design, inaccessible for inspection and repairs or not replaceable without putting the aqueduct out of service for short or long periods; some special pipe castings situated similarly to the valves just mentioned, and permanent ladders in deep gate wells or man-holes which would unavoidably be wet or damp and dark.

Having found metals which seemed well suited to these purposes at prices lower than were anticipated, these metals were used somewhat more extensively than at the outset intended, because it proved economical so to do. Even as restricted, the total number and weight of these parts to be made of incorrodible metal became impressively large on so great a system of works as the Catskill water supply. In numbers, the bolts and other parts ran far into the thousands and their weight aggregated about 3,000,000 pounds. Of this total weight, castings ranging from a few ounces to 22,000 pounds each amounted to more than 2,000,000 pounds. There were many forgings, ranging from bolts of ordinary sizes to sluice gate stems about 6 inches in diameter, 31 feet long, weighing 3,200 pounds a piece. Rods, plates and shapes made up the balance, some rolled and drawn, others extruded. The total expenditure for the purchase of brass may be roughly approximated at $1,000,000. For descriptions of many of these objects, reference is made to a paper by the author, entitled, "Brass in Engineering Construction," presented to the Municipal Engineers of the City of New York, in November, 1914; also, to numerous articles in the metal trade journals during the past few years, as well as in the engineering periodicals. Accompanying illustrations show a number of them.

Since no simple metal exists which would meet the requirements, naturally the brasses and bronzes, which are among the oldest known alloys, were regarded as the most promising materials. Government bronze (variously called gun metal, com-

position G and 88-10-2), manganese bronze, naval brass, phosphor bronze, Tobin bronze, vanadium bronze, Monel metal and some other alloys all were investigated. Bearing brasses and bronzes for gate and valve seats and similar parts will not enter into this discussion. Common brass was not seriously considered for the parts with which this paper is particularly concerned because of its known corrodibility, under many circumstances. For some of the alloys mentioned, it was claimed that they could be used as steel is used and that they equalled or exceeded steel in strength. These claims were supported by the reports of tests made in government, college and professional testing laboratories and by records of experience. After careful consideration, manganese bronze was selected for general use for the purposes mentioned. Although in no one case had this metal been used so extensively as was proposed for the aqueduct, excepting possibly in the Navy, it seemed to have an excellent record in both castings and wrought shapes. It had been in use for thirty years or more. Not only the United States Navy but other navies had, for many years, used manganese bronze propellers, some of which were very large castings, and manganese bronze bolts. Information was diligently sought from responsible superintendents, metallurgists and officers of large manufacturing companies, and from engineers and other users, in many different places, and the counsel of such men was frequently asked and freely given while designing and specification writing were in progress.

All the brass for Catskill aqueduct was obtained under specifications and was inspected. Many bolts and other relatively small articles and a few of the large ones were furnished under special items in general contracts for the construction of large portions of the aqueduct, but the major portion of the brass, and particularly the large valves and special pipe castings, were purchased under a few separate contracts. These numerous and various brass articles were made by a number of manufacturers in Pennsylvania, New England, New York and New Jersey by methods and equipment of their own selection. Some of these manufacturers of brass have had experience equaling or exceeding, in number of years, the period of manufacture of modern steels.

One of the inherent necessities of the construction of a great system of works like the Catskill water supply is that the whole must be completed, or substantially so, before a real working test, or any approximation of such a test, can be made of any important part, or of any large piece of equipment. Their sizes commonly forbade any preliminary test under conditions which would simulate those of actual use. Nevertheless, such hydrostatic and other tests as seemed feasible were made in addition to the customary tensile and other physical tests.

Specifications, with a few exceptions, stipulated the desired physical qualities, without giving, at the same time, metallurgical composition. Methods of manufacture were rarely specified or even indicated. The manufacturer was believed to be more competent to determine these from his long and varied experience, than was the engineer. Some typical extracts from the specifications are given below and, following them, selected representative results of physical tests of the materials furnished.

Bronze Castings:

> All bronze castings shall be made of new metal, shall be free from objectionable imperfections and shall conform accurately to patterns. When the castings are being machined, if the metal shows signs of imperfect mixing, they shall be rejected. Unless otherwise called for in the specifications, or upon the drawings, bronze where indicated upon the drawings shall mean manganese bronze.

Manganese Bronze:

> All manganese bronze shall be equal to Spare's, Parsons' or Hyde's manganese bronze, and shall have a tensile strength of not less than 65,000 pounds per square inch, an elastic limit of not less than 45 per cent. of the ultimate tensile strength and an elongation of not less than 25 per cent. (in 2 inches).

Brass Rivet Rod:

Tensile strength of brass rivet rods shall be not less than 55,000 pounds per square inch. The elastic limit shall be not less than 30,000 pounds per square inch, and the elongation not less than 20 per cent.

Stems:

The main gate stem shall be of manganese bronze, or other bronze of approved composition, of such dimensions that when placed in tension under a load in pounds equal to the area of the valve opening in square inches multiplied by 125, the minimum cross-section of the stem shall have a resultant unit stress not exceeding two-thirds the elastic limit of the material used. These stems shall be turned straight and true and shall have all threads lathe-cut.

Rolled Bronze:

Whenever the term "Bronze" is used in these specifications in a general way, or on the drawings, without qualification, it shall mean manganese or vanadium bronze, or monel metal. Whenever the characteristics of any material are not particularly specified, such material shall be used as is customary in first-class work of the nature for which the material is employed.

The minimum physical properties of bronze shall, except as otherwise specified, be as follows:

Castings:

Ultimate tensile strength	65,000 lb. per sq. in.
Yield point	32,000 " " "
Elongation	25 per cent.

Rolled material, thickness one inch and below:

Ultimate strength	72,000 lb. per sq. in.
Yield point	36,000 " " "
Elongation	28 per cent.

Rolled material, thickness above one inch:

Ultimate strength ....70,000 lb. per sq. in.
Yield point ....35,000 " " " "
Elongation .... 28 per cent.

After being forged into a bar, rolled or forged bronze shall stand, first, hammering hot to a fine point; second, bending cold through an angle of 120 degrees to a radius equal to the thickness of the bar.

TYPICAL RESULT OF PHYSICAL TESTS OF BRASSES USED ON THE CATSKILL AQUEDUCT.

Yield, pounds per square inch.	Ultimate strength, pounds per square inch.	Elongation, per cent.	Reduction, per cent.	Fracture.
Forgings:				
36,500	73,150	41.5	46.8	Irreg.
37,500	75,750	35.5	43.9	"
38,250	76,900	35.5	46.8	"
52,500	77,100	31.0	...	" silky
49,300	76,150	33.5	...	Silky cup
50,000	75,350	31.0	...	Irreg. silky
43,500	70,000	34.0	47.0	Irreg.
36,000	67,500	40.5	43.5	"
Castings:				
39,650	66,000	40.0	...	Irreg. gran.
43,100	68,850	25.0	...	" "
39,950	68,050	29.0	...	" "
33,000	66,250	25.0	25.4	"
32,750	67,500	30.0	27.7	"
32,250	67,200	36.0	34.1	"
39,500	69,100	39.0	...	" silky
47,500	71,000	40.5	...	" gran.
50,000	70,000	34.0	...	Ang. silky
33,250	73,000	30.0	28.5	Irreg.
33,000	73,500	35.0	34.0	"
34,500	73,250	40.0	36.5	"
43,250	69.950	40.5	...	Ang. silky

Yield, pounds per square inch.	Ultimate strength, pounds per square inch.	Elongation, per cent.	Reduction, per cent.	Fracture.
Castings:				
44,000	70,050	34.0	...	Irreg. deep cup fine gr.
42,500	69,500	37.5	...	Ragged cup, silky
46,000	69,850	33.0	...	Ang. cup silky
44,000	69,600	40.5	...	Ang. fine gran.
41,500	72,350	36.5	...	Irr. ½ cup silky
40,000	68,000	38.0	...	Forked silky
42,000	67,000	37.0	...	Ang. silky
43,750	69,050	37.0	...	Deep fork silky

Some brass and bronze pipes were required in various parts of the Catskill waterworks, and so it was specified, for example, that—

"* * * The Contractor shall furnish and deliver the bronze pipe for the operating piping for the section valve cylinders and other miscellaneous bronze, brass or copper pipe * * *."

"The pipe shall be seamless drawn, semi-annealed, iron-pipe-size tubing of the sizes shown on the contract drawings or ordered. It shall be made of the bronze specified in the general sections, or of an approved commercial bronze. All pipe furnished under this item shall be free from season cracks, surface cracks, or other defects.

"When the pipe is finished, ready for shipment, the Engineer will subject about one per cent. of the lot, taken at random, to the following tests:

"1st. Each test pipe shall stand threading perfectly, with a die with the usual thread for the size of the pipe.

"2nd. After annealing, the end of each test pipe shall stand being flattened by hammering until the sides are brought

parallel, with a curve on the inside at the ends not greater than twice the thickness of the metal, without showing cracks or flaws.

"3rd. After annealing, each test-piece shall have a piece 3 inches long cut from it, which, when split, shall stand opening out flat without showing cracks or flaws."

In spite of the care exercised, the brass furnished has proved distinctly unsatisfactory in most of the uses to which it has been put in the Catskill aqueduct. No suspicions of definite troubles were developed until the fall of 1913. About that time numerous bolts and rods were found cracked. The number and character of the failures detected strongly suggested that they were not merely accidental or occasional. Since that time, additional failures have been coming to light almost continually. Failures were the more disturbing because the specifications had been drawn carefully, in the light of information then in hand, and practically all the metal accepted had been carefully inspected and tested. Some chemical analyses had been made also. Much of the metal accepted had shown physical qualities far in excess of the specified requirements. Furthermore, the objects which are being found defective were furnished by manufacturers of long experience and established reputation. It is quite improbable that these manufacturers had not, at least in the main, honestly endeavored to fulfill the requirements of their contracts, although they may have been insufficiently informed as to means and methods in some instances, and somewhat influenced by commercial considerations.

That apparently sound brass pipes and brass wire of some kinds would occasionally crack, without evident reason, was known to the engineers of the Board of Water Supply, as were various explanations of this phenomenon; but leading manufacturers of brass pipe had learned how to modify the process of manufacturing so as to overcome these troubles in large measure. Nevertheless, some failures have been experienced with the pipes furnished even by reputable manufacturers. There would seem to be but small excuse for supplying other than dependable brass (or bronze) pipe nowadays, as correct methods of manufacture are claimed to be well known in the trade.

Defects in large plates, in bolts, rods, side-bars and rungs of ladders, and in similar wrought objects constituted the most important and numerous failures discovered up to the spring of 1915. Many of these articles had not yet been installed, but had been in storage, in some instances, for many months. Many were still in their packing cases. Defective bolts and rods usually had circumferential cracks, partially or all the way around. Flats had cracks starting in from an edge with a characteristic curvature. Some cracks were very fine and only superficial; others gaped open and penetrated the metal deeply. In some cases, the whole or nearly the whole cross-section was affected in bolts from ½ to 2¼ in. in diameter; some were found severed, and others broke upon being subjected to a light blow or pull. Cracking has been progressive in some instances, and in numerous cases specimens which, on first examination seemed free from this cracking, developed it later; two or three years have passed in some cases before the defects developed so as to be detected.

Finally, these defects were found to be so general, were so distributed through the output of various manufacturers, and were so common in the different kinds of brass that all wrought brass fell under suspicion. Consequently, bolts in all important places, even when seemingly sound, ladders, pipes and other wrought brass objects have been or are being replaced. Following the first discovery of the cracking, replacements were directed to be made with brass produced by methods avoiding cold working, and special attention was given to the production of this material. It was hoped that, by these methods, further trouble of this kind would be avoided, but, unfortunately, this has not proved to be the case. Ultimately there has seemed to be no remedy other than to use steel or iron, with their known disadvantages, burying them in concrete or mortar, wherever this was feasible even at some inconvenience, galvanizing them in other places and using other protective coatings in still other places. Indeed, but for the seriousness of the matter, "bronze" (brass) would be but a laughing-stock among the engineers of the Catskill aqueduct, and many others who have known of their experiences, and among those who, themselves, have had somewhat similar experiences within recent years, for investigation has disclosed

the fact that similar defects have been observed by others in a variety of metals, but, chiefly, in bolts of well known brands of "bronze" furnished by well known manufacturers. That such troubles should suddenly have developed so extensively, or, at least, that they should have become widely known only recently, or that knowledge of such failures, if they have been frequent in years gone by, should have been withheld by the manufacturers, seems incredible. The questions naturally arise:

> Were any changes made in the methods of manufacture or in the ingredients of these alloys about the time that the production of brass for the Catskill aqueduct began?
>
> What were these changes and why were they made?
>
> What changes, if any, have been made by the manufacturers in their processes, materials and methods since the troubles with various brasses and bronzes on the Catskill aqueduct were discovered and made known?
>
> If no changes have been made, is it to be inferred that the manufacturers still believe that the methods and materials used in producing brass for the Catskill aqueduct were satisfactory? If so, how are the failures accounted for?

Large forgings, which include chiefly the stems for large sluice gates and valves, have shown no sign whatever of failure, although they have been repeatedly and carefully examined. Until the spring of 1915, castings were believed to be immune from troubles, excepting those incident to foundry work and of the kinds which might occur in any metal. Since then, however, a number of castings from at least three different foundries producing manganese bronze have been found cracked. All these castings, before acceptance, had been subjected to hydrostatic test pressures of 200 or 300 pounds per square inch, for a half hour or more, and, of course, appeared to be satisfactory at the time of preliminary acceptance. Some months later, after having been placed in the structures, some of these castings leaked under pressures of only a few pounds. In some castings the

cracks have grown longer as time has elapsed, and in some, with the passage of time, additional cracks have been discovered. These cracks are fine and often difficult to detect on the surface until the casting is put under hydrostatic pressure. In most cases, indeed in nearly all, these cracks appeared to be close to, or in a repair made by the method of "burning-in," or welding. Extended, recent inquiries show that this practice is of long standing and of general use in reputable brass foundries. Methods vary widely in detail. Our investigation has not yet proceeded far enough to justify any further statement, but it is evident that the application and details of such methods of repair, and some other details of brass foundry practice, need to be carefully studied by foundry metallurgists.

Troubles with wrought brass or bronze, experienced on the Catskill aqueduct may be classified as follows: *First,* breaks from stress, (a) initial stress, due to methods of manufacture or fabrication, (b) applied stress, due to use; *second,* damage by wrong heat treatment, as in forging, bending, flanging, upsetting and annealing. Damage of the secod class results entirely from lack of skill, knowledge or care on the part of the manufacturer or fabricator.

Designers have been misled to some degree by the representations of the manufacturers that certain bronzes (brasses) possessed great strength and other excellent qualities, and in some cases would perform practically the same duty as steel, or a little more. Seemingly both maker and user have misinterpreted the results of the usual standard laboratory tests, from lack of knowledge of characteristics of the copper alloys not revealed by such tests. Experience on the Catskill aqueduct indicates that the bronzes (brasses) as supplied under contract, with careful inspection following the established methods, would not perform the expected duty. Indeed, as these investigations have proceeded it has become evident that the engineer's present necessity is not merely an explanation of certain failures of brass, but a fundamental knowledge of the physical characters and capacities of this group of alloys,—knowledge which will be a safe and dependable guide in their manufacture, inspection and use.

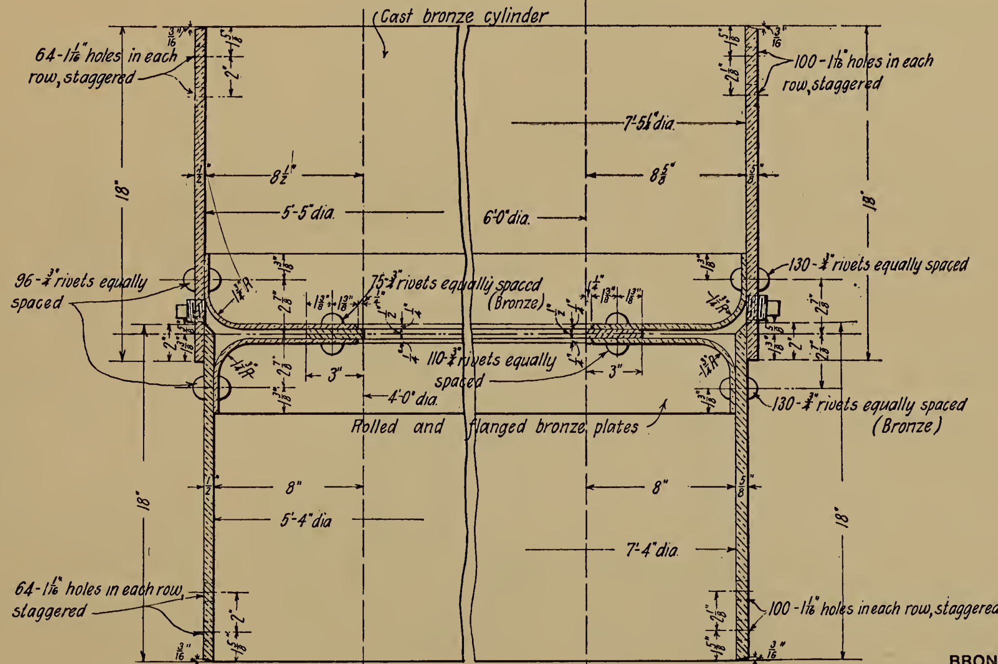
As our investigations and experience have progressed, not merely unfortunate foundry and shop ignorance of important details of manufacture of copper alloys and, possibly, suppression of significant information, have come to light, but, also, seemingly, a deplorable lack of definite and sufficiently complete knowledge of some of the fundamental characteristics of these alloys. Clearly, the art of brass-making had not surely progressed so far as was confidently claimed. Before designing and constructing, civil and mechanical engineers can venture to use brass extensively for important works where it would be subjected to other than very low stresses, some questions will have to be conclusively answered by manufacturers and metallurgical specialists. The author ventures to repeat the questions, which he has stated more than once before, and to add to them:

> Can a brass or bronze of high tensile strength be reliably produced which can be used safely for important, permanent structures in such parts as bolts and other rolled, drawn, extruded or forged shapes?
>
> What should be the specifications for such brasses or bronzes?
>
> What inspection methods and tests should be used?
>
> By what tests can the tendency to subsequent failure be detected at any time after manufacture?
>
> What working stresses may be used safely for these various alloys?
>
> Will these brasses, or bronzes, deteriorate by reason of constantly applied or frequently repeated stress—i. e., will they fail from fatigue?
>
> Can large, hollow, manganese bronze castings be made of such forms as water and steam valves?
>
> If manganese bronze is not suitable for such castings, what composition can be used?
>
> Can any repairs of brass castings, to be subjected to hydrostatic pressure, be safely made by any processes of

"burning-in," or welding, now commonly used? If so, what relation has the shape and size of the casting to the methods and means to be employed?

What tests can be applied to prove that such a repair has been successfully made and that later a crack will not develop because of it?

In closing, the author would disclaim any knowledge of metals other than as a civil engineer user, and that which he has recently acquired by extended inquiry. The metallurgical questions involved in the experiences narrated above are being investigated by Dr. George K. Burgess and Dr. P. D. Merica with their staff in the Bureau of Standards, Department of Commerce, Washington. Mr. Ernst Jonson, engineer inspector of the Board of Water Supply has also devoted much time and study to these problems. These men have presented papers to several of the technical societies and journals, stating some of the results of their investigations. Doubtless, also, metallurgists connected with the manufacturers have been giving attention to these problems and could contribute to the general information, if they would. Possibly the time is not yet ripe for such statements, pending the further progress of experiments on an extensive scale. The demand for a strong, dependable, incorrodible metal, which can be cast and wrought, is so great that there would be a large use for it in important engineering works, even at a price several times that of iron or steel. The statements above have been made for the purpose of helping toward the production of such a metal and toward developing suitable methods of manufacturing, using, specifying and testing it.



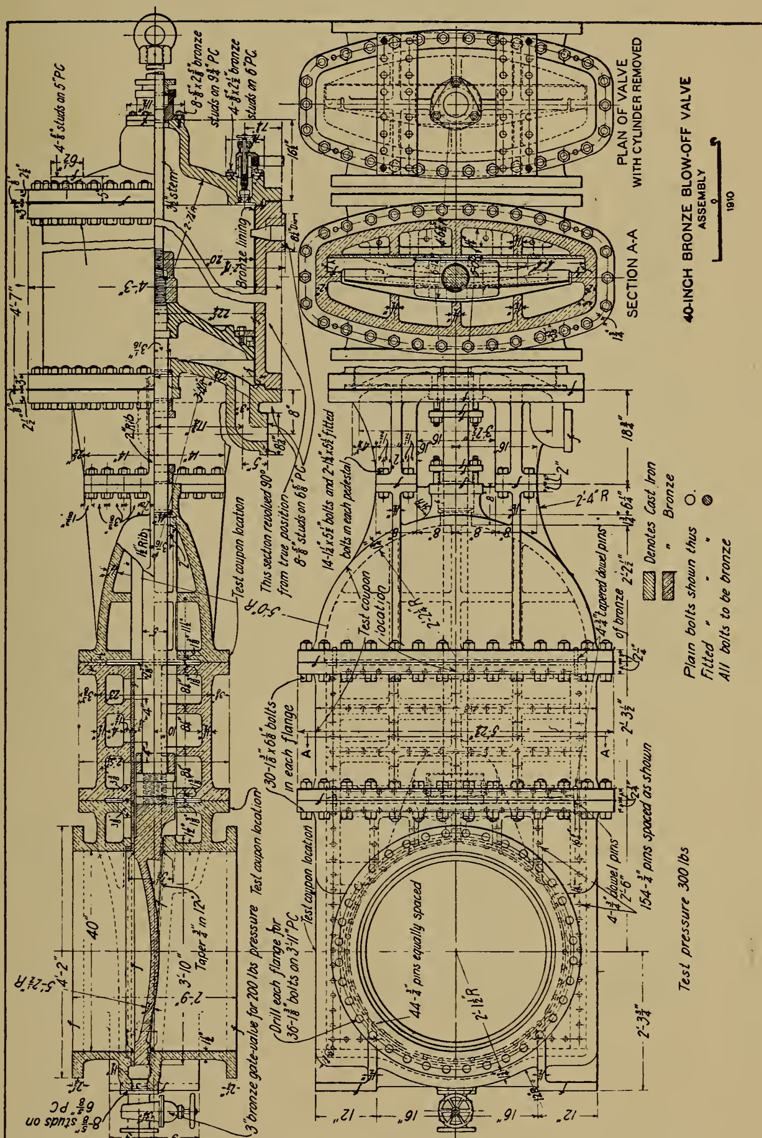
FOR 48" RISER
Standard weight 1530 lbs

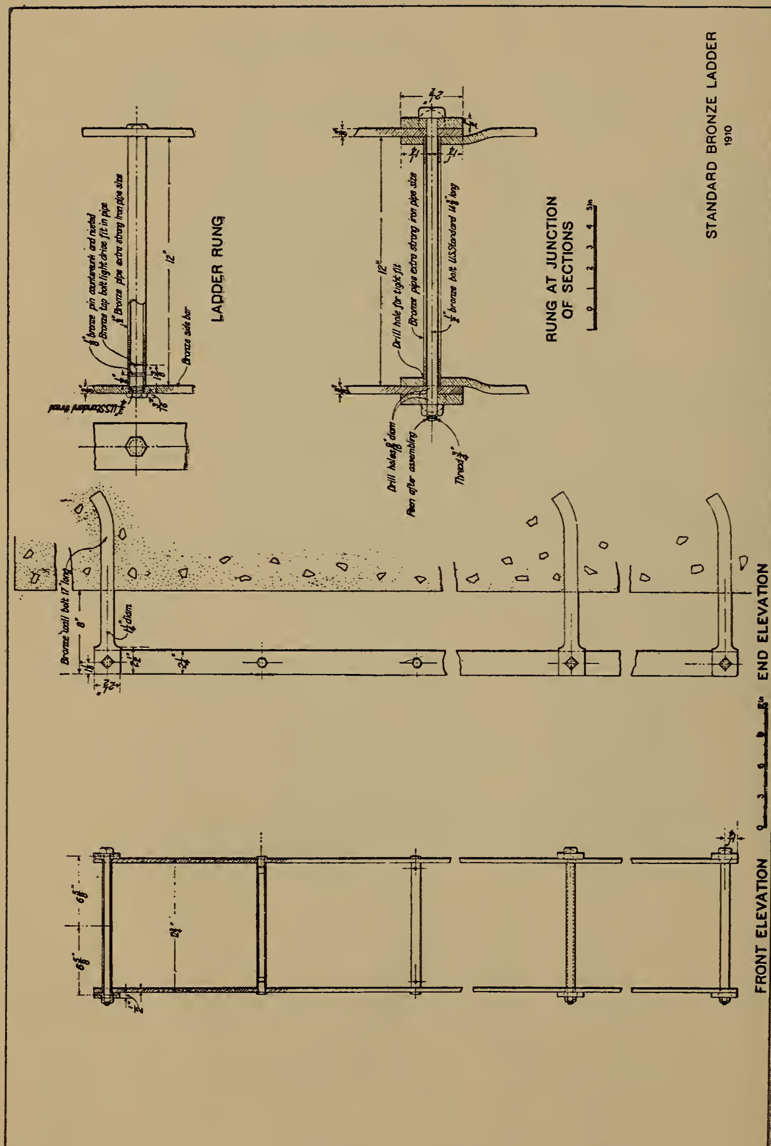
FOR 72" RISER
Standard weight 2485 lbs.

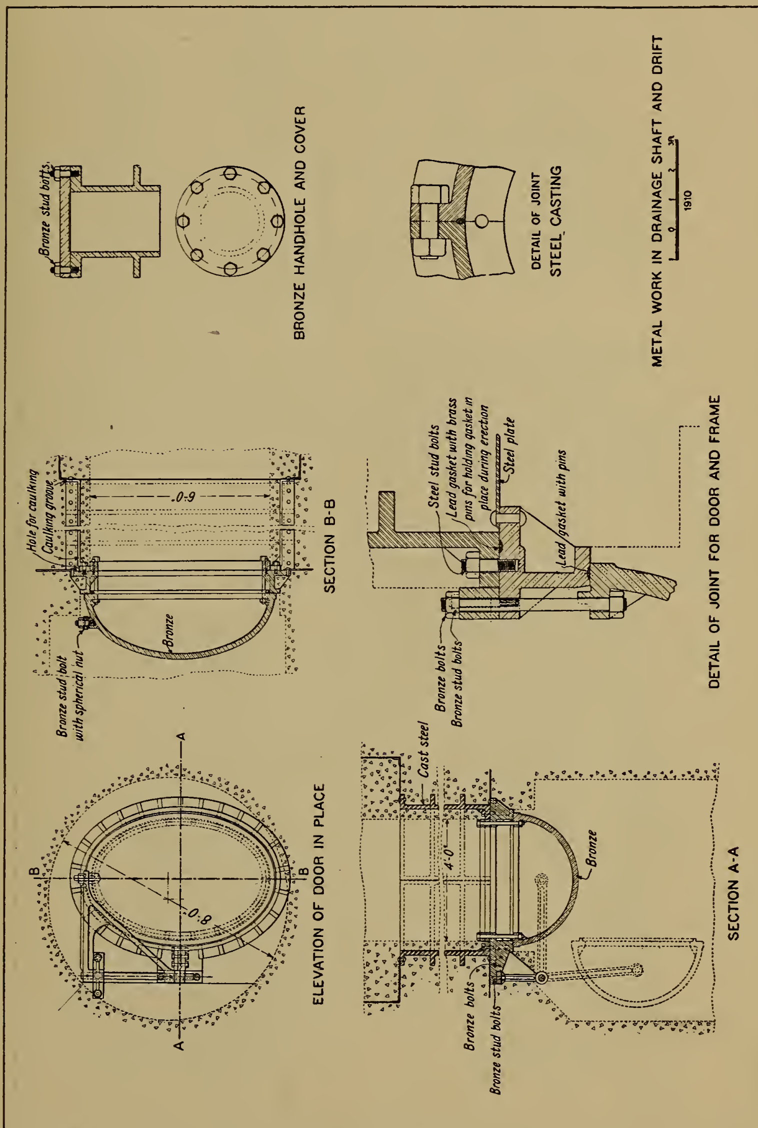
BRONZE EXPANSION-JOINTS IN STEEL INTERLINING OF RISERS

0 3 6 9 12 In

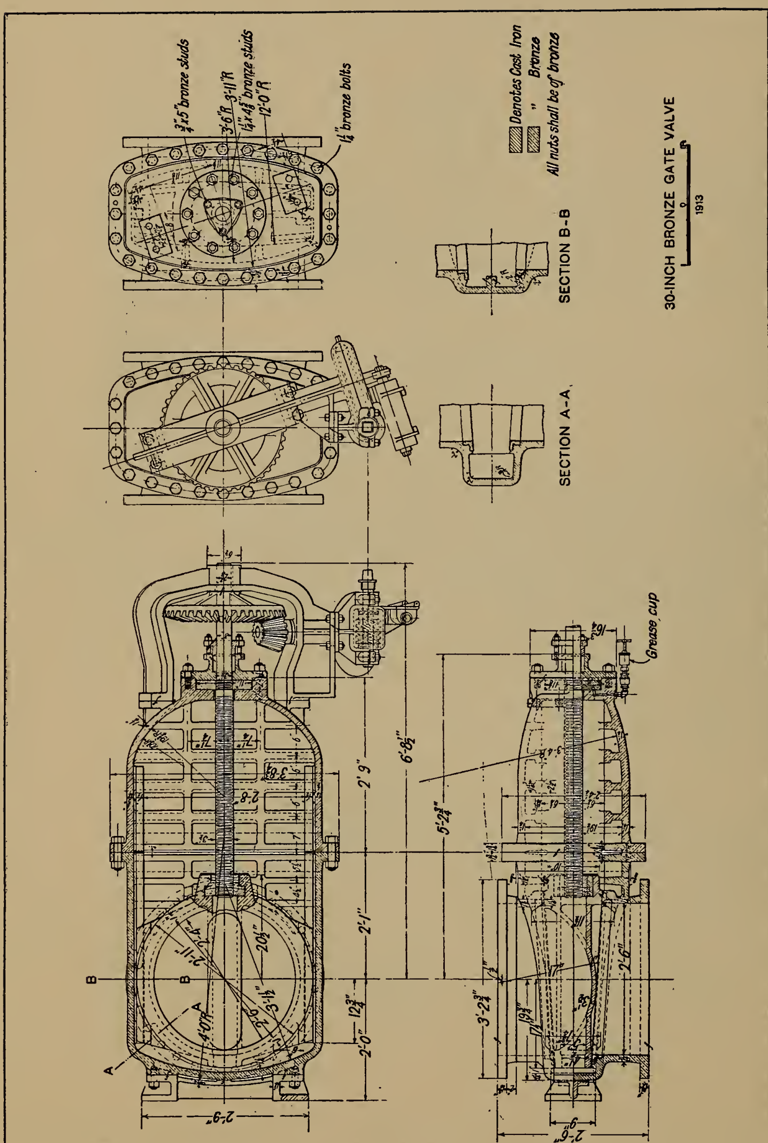
1912


40-INCH BRONZE BLOW-OFF VALVE
ASSEMBLY
1910
PLAN OF VALVE
WITH CYLINDER REMOVED
SECTION A-A
Denotes Cast Iron
" Bronze
Plain bolts shown thus
Fitted " "
All bolts to be bronze
Test pressure 300 lbs
Test coupon location
Bronze lining
This section revolved 90° from true position
Drill each flange for
in each flange
pins equally spaced
pins spaced as shown
bronze gate-valve for 200 lbs pressure

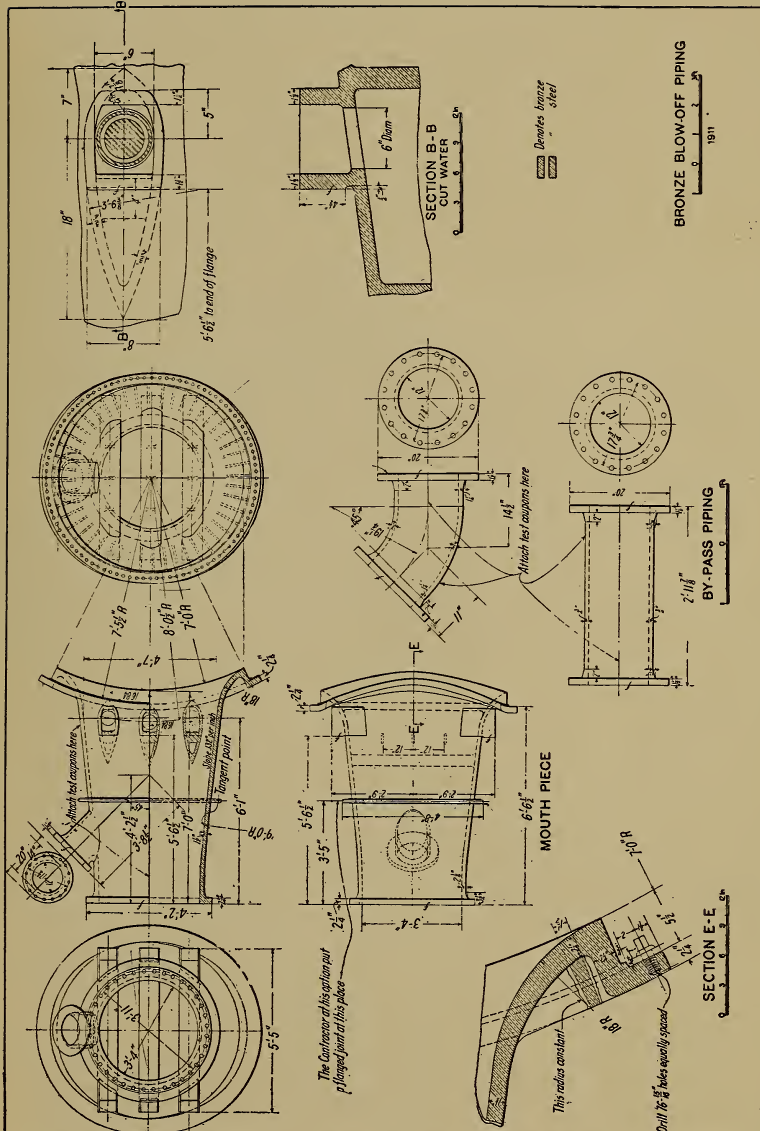

STANDARD BRONZE LADDER
1910
LADDER RUNG
RUNG AT JUNCTION
OF SECTIONS
FRONT ELEVATION
END ELEVATION
Bronze side bar
Drill hole for tight fit
Peen after assembling



METAL WORK IN DRAINAGE SHAFT AND DRIFT

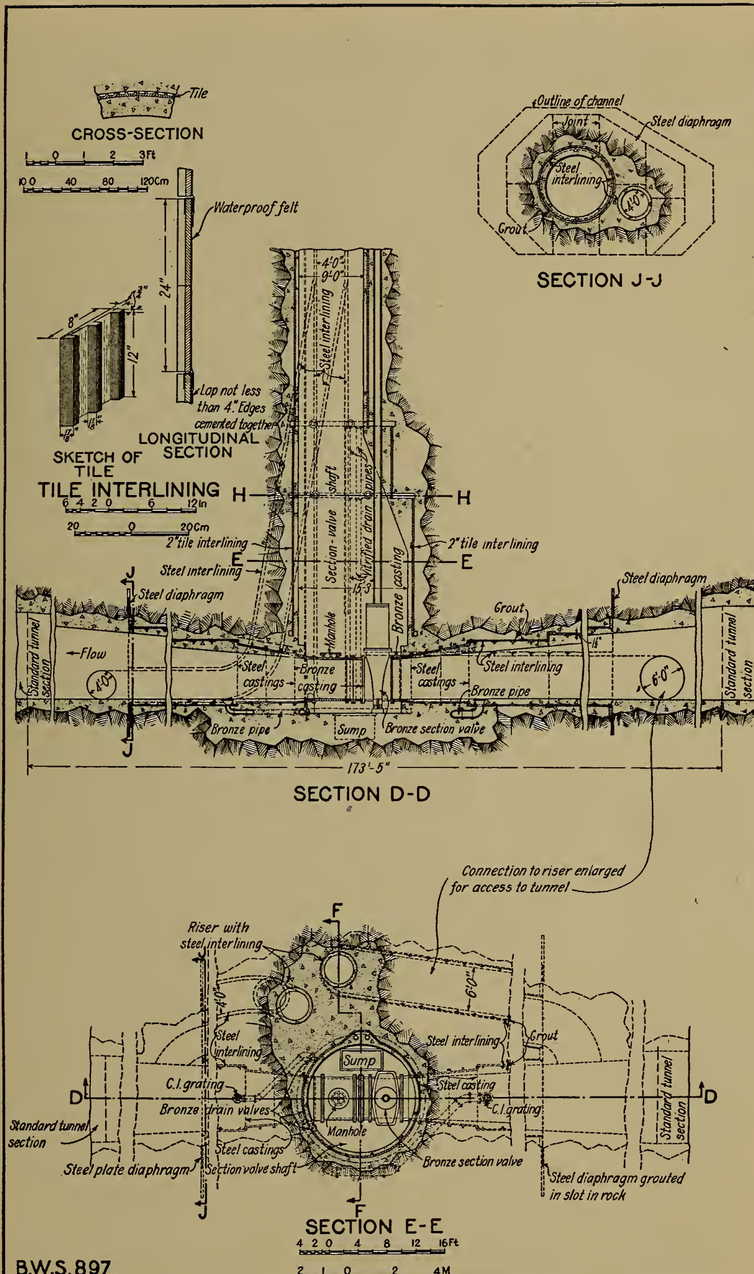


30-INCH BRONZE GATE VALVE


BRONZE BLOW-OFF PIPING
1911
SECTION B-B
CUT WATER
Denotes bronze
" steel
5'-6½" to end of flange
BY-PASS PIPING
Attach test coupons here
MOUTH PIECE
Tangent point
The Contractor at his option put p flanged joint at this place
SECTION E-E
This radius constant
Drill 76-15/16" holes equally spaced

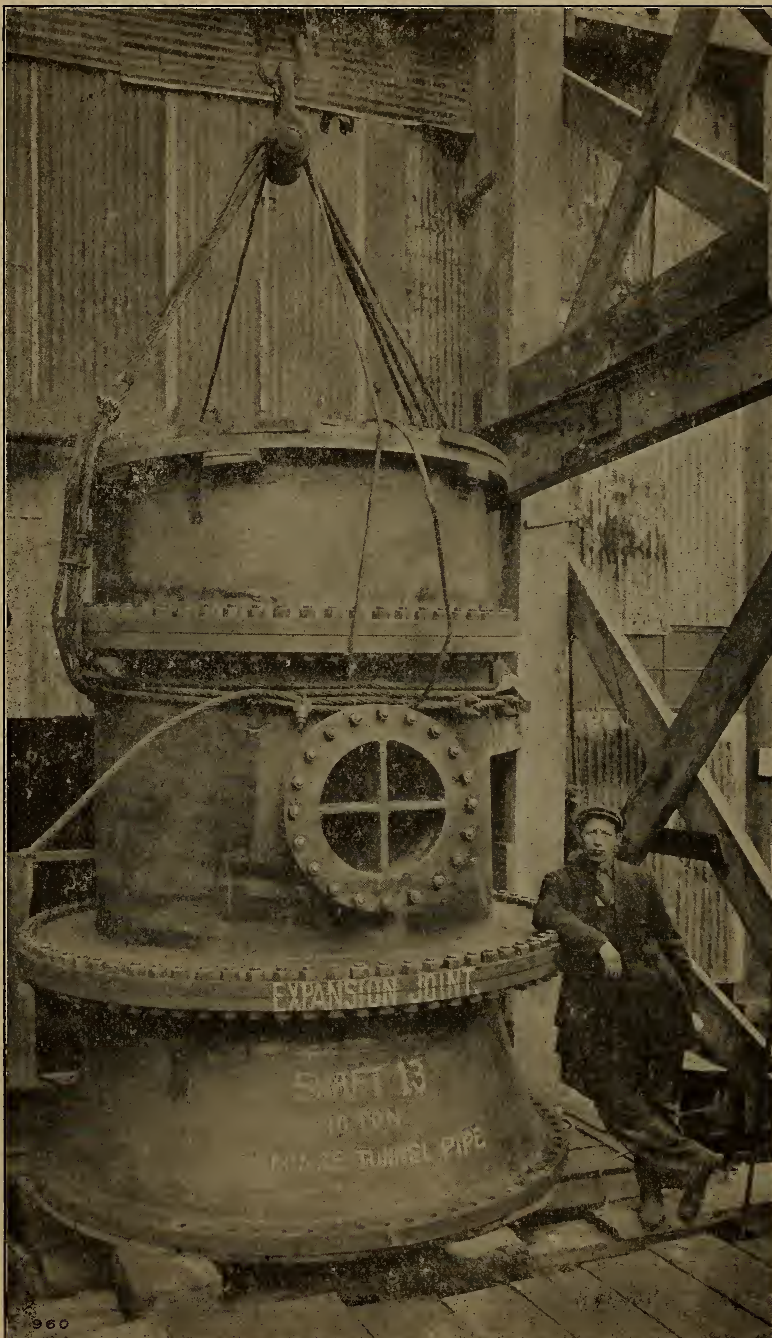
Catskill Aqueduct, City Tunnel.

Interior of a Concrete Chamber at the Top of a Shaft, Showing the Bronze Shaft Cap with Cover Removed, and Two 30-in. Bronze Gate Valves Bolted to the Side Outlets of the Shaft Cap.

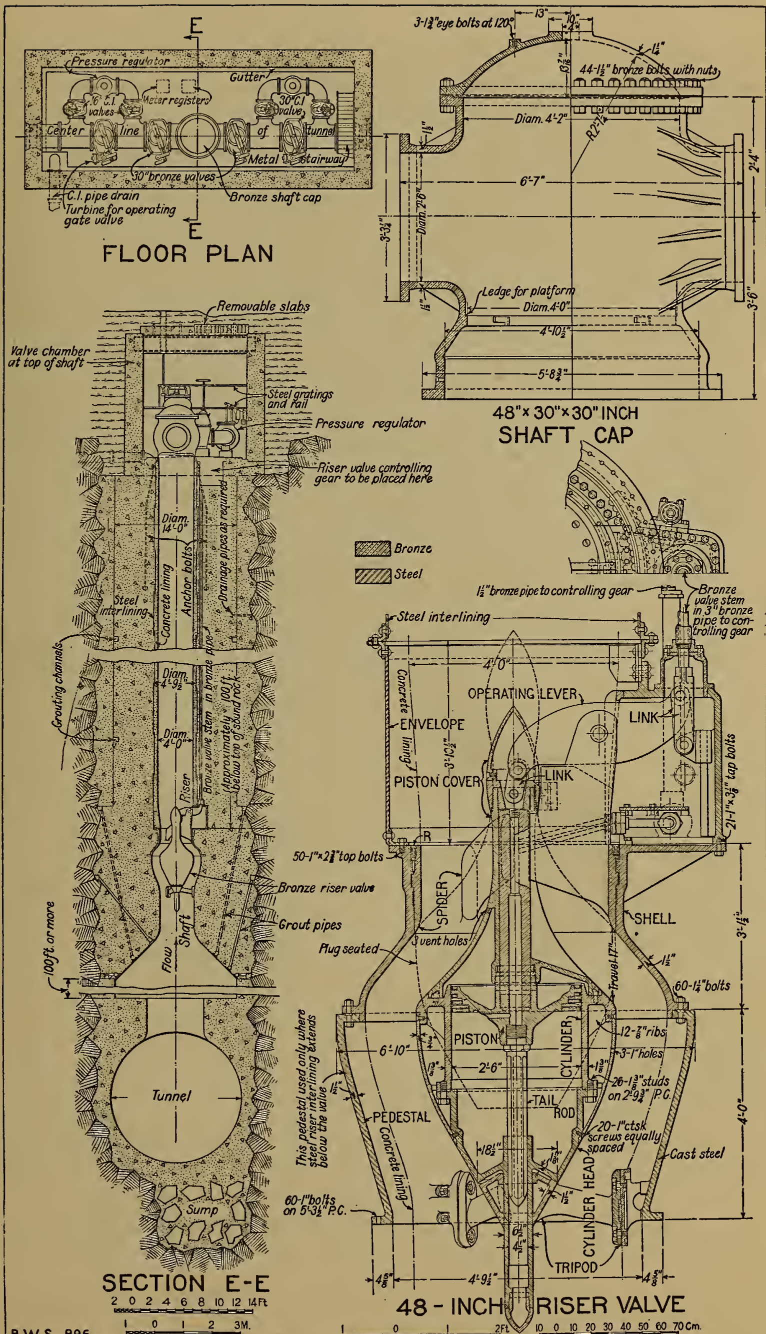


Catskill Aqueduct, City Tunnel.

Section-Valve Shaft Showing 66-in. Bronze Section Valve and Adjacent Bronze Castings, and Method of Reducing the Diameter of the Tunnel to that of the Valve.

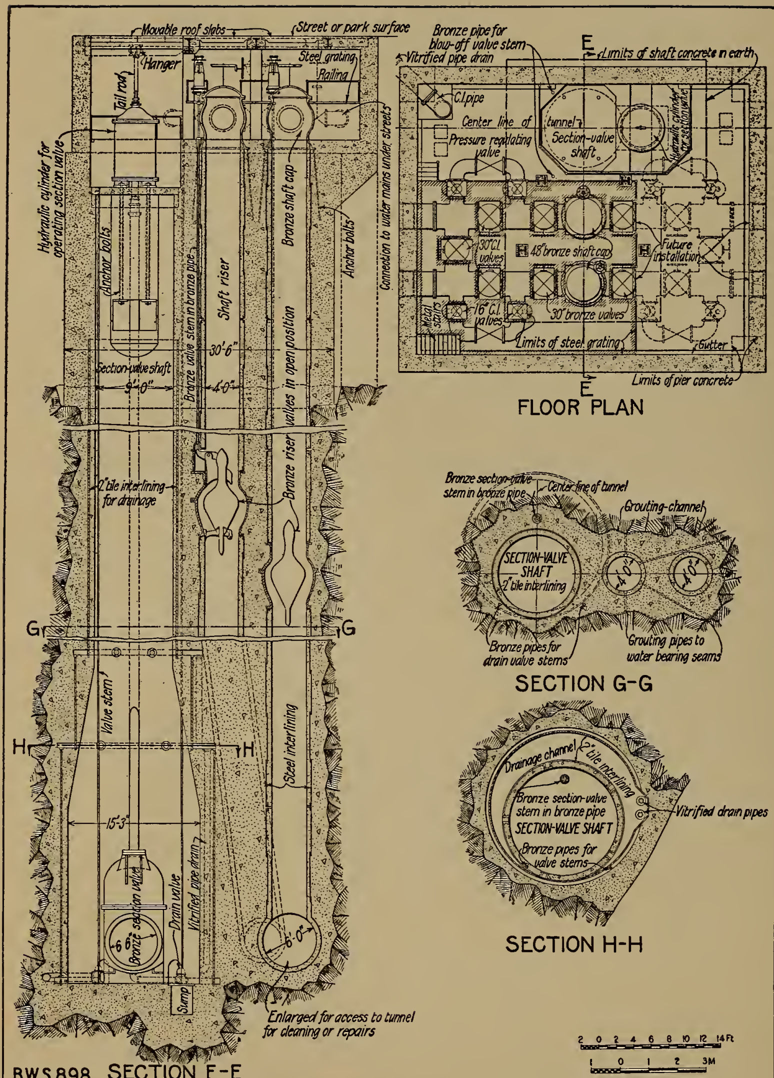


Catskill Aqueduct, City Tunnel.
Bronze Reducer Pipes suspended over the Shaft ready to be lowered into position.



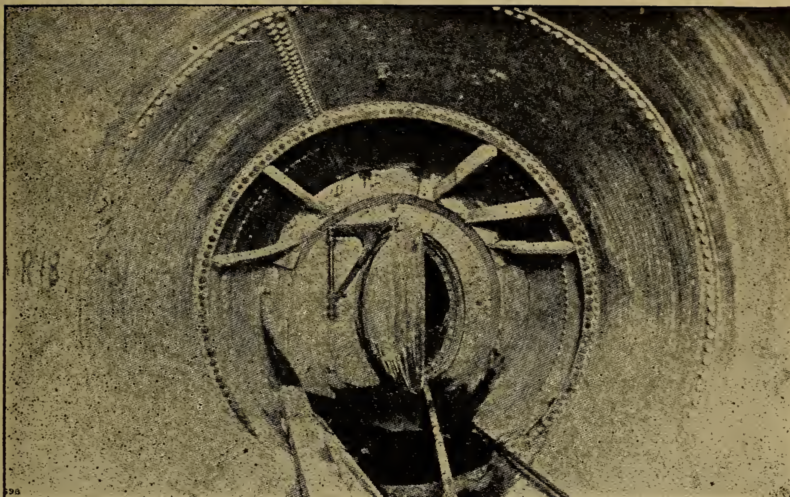
Catskill Aqueduct City Tunnel.

Typical Shaft and Chamber Showing Connection from the Tunnel to the Water Mains under the Streets; also a Shaft Cap and Riser Valve.



Catskill Aqueduct City Tunnel.

Plan and Longitudinal Section of a Section-Valve Shaft Showing Special Arrangement of Risers and Positions of Riser Valves with Steel Pedestals.



Catskill Aqueduct, Pressure Tunnels.

Bronze Door in Drift Connecting a Drainage Shaft with the Tunnel. When Door is Closed, Water from the Tunnel is Shut Off from the Shaft. Six of These Have Been Used.